

SPREAD SPECTRUM MULTIPLE ACCESS CODES AND CODE GROUPS
GENERATED BY ROTATION TRANSFORMATION

5 The present application is a continuation-in-part of, and claims priority under 35 U.S.C. §§ 120 and 365(c) to co-pending PCT application bearing application number PCT/CN00/00092, filed April 18, 2000, and designating multiple countries including the United States, but was not published in English under PCT Article 21(2).

10 Related Applications

 The present application is related to PCT application bearing PCT/CN00/00179, filed June 26, 2000, and co-pending United States patent application entitled "Generation of Spread Spectrum Multiple Access Codes with Zero-Correlation Windows", filed herewith and bearing attorney docket number 10748-0004-999. The aforementioned United States
15 patent application is hereby incorporated by reference in its entirety.

Field of the Invention

 The present invention relates generally to wireless spread spectrum technology and digital mobile communication technology, and more particularly to a method for generating
20 spread spectrum multiple access codes, and a method of orthogonal transformation between multiple access code groups.

Background of the Invention

 Spread spectrum technology, particularly code division multiple access (CDMA)
25 technology, has become increasingly important in wireless communication because spread spectrum technology can provide a larger system capacity than other multiple access methods.

 In a spread spectrum communication system, the selection of multiple access code
30 directly influences the system's capacity, interference cancellation, access speed and switching speed, etc. Each user in a spread spectrum communication system has his own special spread spectrum multiple access code for addressing and multiple access purposes. Generally speaking, within a cell (or sector), spread spectrum multiple access codes assigned to different users have the property that they are completely orthogonal or nearly
35 completely orthogonal with each other, that is, the sum of the products of each element of

one code with the corresponding element of the other code equals to or approaches zero. At the same time, spread spectrum multiple access codes used in one cell should also be as orthogonal with those used in a different cell as possible. This is not only for identifying cells (or sector) and users, but also for reducing interference between neighbor cells (or sector) and among user channels. This is because a user station usually receives not only signals from its own cell's base station, but also signals from its neighboring cells.

Therefore, for any system based on the code division multiple access (CDMA) technology, the spread spectrum multiple access codes used in neighboring cells (or sector) should be as orthogonal as possible. The orthogonality property is usually described mathematically by the correlation function between multiple access codes. The smaller the value of the correlation function, the better is the orthogonality and the larger is the difference between two spread spectrum multiple access codes.

At present, the most popular method for generating spread spectrum multiple access codes for use in different cells is to scramble the basic orthogonal spread spectrum multiple access codes using different offsets of a long pseudorandom (PN) sequence. A different offset of the long PN sequence is used in different cells. For example, consider the following four mutually and completely orthogonal spread spectrum multiple access codes:

+	+	+	+
+	-	+	-
+	+	-	-
+	-	-	+

In the example above, "+" represents digital +1 and "-" represents digital -1; and, each row represents a basic spread spectrum multiple access code. As is evident from comparison of the codes, each code is orthogonal with every other code, because the sum of products of each element of one code with the corresponding element of every other code is zero.

When these codes are scrambled by multiplying them with - + + + and + + + -, respectively, the following two groups of spread spectrum multiple access codes are generated:

Group 1

- + + +
- - + -
- + - -

5 - - - + (scrambled by - + + +), and

Group 2

+ + + -
+ - + +
+ + - +
+ - - -

(scrambled by + + + -).

Since the scrambling process performs the same operation on each element at the same position in a code word, the relation among the elements at the same position in any intra-group pair of code words is not changed by the scrambling process. As a result, within each of the two newly produced groups of spread spectrum multiple access codes, the spread spectrum multiple access codes within each group remain completely orthogonal with each other. But as between the two groups, since different scrambling functions were used, the relation among the elements at the same position in any inter-group pair of code words will change at those locations where the scrambling codes differ. As a result, code words in Group 1 may no longer be completely orthogonal with code words in Group 2. For example, the code word - - - is not orthogonal with the code word + + - +.

The scrambling transformation approach, although effective in generating groups of orthogonal multiple access codes, has the following disadvantages:

1. The code groups obtained by scrambling may not retain the non-periodic auto-correlation and cross-correlation characteristics of the initial code group.
2. Some codes in the initial code group may not be completely orthogonal with codes obtained by scrambling.
3. Scrambling will result in non-orthogonal codes if the codes of the initial code group are not orthogonal with each other. Thus, the initial orthogonal code group must be carefully chosen.

Accordingly, there exists a need for a method and apparatus for generating the spread spectrum multiple access codes without the above-mentioned disadvantages.

Summary of the Invention

5 The present invention provides a method and apparatus for generating spread spectrum multiple access codes that is more advanced than the scrambling transformation approach. According to some embodiments of the invention, a real number or complex number sequence of any length can be used to form orthogonal groups of spread spectrum multiple access codes. An initial code group may be used to form code groups that retain the non-periodic auto-correlation and cross-correlation characteristics of the initial code
10 group. Furthermore, codes in the code groups obtained according to embodiments of the present invention are completely orthogonal with each other and with codes in the initial code group.

The present invention, in some embodiments, provides a method and apparatus for
15 generating groups of spread spectrum multiple access codes from an initial group of codes. After the transformation, the resulting code groups retain the correlation characteristics of the initial code group. These characteristics include periodic, non-periodic and hybrid auto-correlation characteristics; and periodic, non-periodic and hybrid cross-correlation characteristics. The codes of the resulting code groups and the codes of the initial code
20 group are mutually orthogonal if the codes in the initial code group are substantially orthogonal with each other.

An embodiment of the present invention is a method of generating a spread spectrum multiple access code using orthogonal rotation that includes the following steps:

- 25 • Select a nonzero sequence with N elements, $\mathbf{a}_0 = [a_{00}, a_{01}, a_{02}, \dots, a_{0N-1}]$, where $N \geq 2$.
- Select a set of basic rotation angles $\alpha_1, \alpha_2, \dots, \alpha_{N-1}$ each of which is applied to a corresponding element of the sequence \mathbf{a}_0 . The sum of the basic rotation angles equals $2n\pi$, where n is an integer.
- 30 • Rotate the sequence \mathbf{a}_0 by an integer multiple of the basic rotation angles to form a new sequence. Using different integers between 1 and N-1, the sequence \mathbf{a}_0 may be rotated (N-1) times to obtain (N-1) new sequences.

Together with the initial sequence \mathbf{a}_0 , the following N sequences result:

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$$\mathbf{a}_0 = [a_{00}, a_{01}, a_{02}, \dots, a_{0N-1}]$$

$$\mathbf{a}_1 = [a_{00}, a_{01}e^{j\alpha_1}, a_{02}e^{j\alpha_2}, \dots, a_{0N-1}e^{j\alpha_{N-1}}]$$

$$\mathbf{a}_2 = [a_{00}, a_{01}e^{j2\alpha_1}, a_{02}e^{j2\alpha_2}, \dots, a_{0N-1}e^{j2\alpha_{N-1}}]$$

⋮

$$5 \quad \mathbf{a}_{N-1} = [a_{00}, a_{01}e^{j(N-1)\alpha_1}, a_{02}e^{j(N-1)\alpha_2}, \dots, a_{0N-1}e^{j(N-1)\alpha_{N-1}}]$$

The above sequences are mutually orthogonal and constitute an orthogonal spread spectrum multiple access code group.

Another embodiment of the present invention is a method based on orthogonal rotation for generating a spread spectrum multiple access code group. In this embodiment, the method includes the following steps:

- Take an orthogonal code group with M sequences each having N elements,

$$20 \quad \mathbf{B}^{T_0} = \begin{bmatrix} \mathbf{b}^{T_0} \\ 0 \\ \mathbf{b}^{T_1} \\ \vdots \\ \mathbf{b}^{T_m} \\ \vdots \\ \mathbf{b}^{T_{M-1}} \end{bmatrix},$$

where

$$\mathbf{b}_m^{T_0} = [b_{m0}, b_{m1}, b_{m2}, \dots, b_{mN-1}], \quad m = 0, 1, 2, \dots, M-1.$$

- Select a set of basic rotation angles $\alpha_1, \alpha_2, \dots, \alpha_{N-1}$ each of which is applied to a corresponding elements of the code group. The sum of the basic rotation angles equals $2n\pi$.
- Rotate each element of the code group by the same integer multiple of an associated one of the basic rotation angles to form a new orthogonal code group.

Using different integer multiples between 1 and N-1, the orthogonal code group \mathbf{B}^{T_0} may be rotated (N-1) times to form (N-1) new orthogonal code groups. Together with the initial code group, the following N orthogonal code groups result:

$$35 \quad \mathbf{B}^{T_0}, \mathbf{B}^{T_1}, \mathbf{B}^{T_2}, \dots, \mathbf{B}^{T_{N-1}},$$

$$\text{where } \mathbf{B}^{T_n} = \begin{bmatrix} \mathbf{b}_0^{T_n} \\ \mathbf{b}_1^{T_n} \\ \vdots \\ \mathbf{b}_m^{T_n} \\ \vdots \\ \mathbf{b}_{M-1}^{T_n} \end{bmatrix},$$

$$\mathbf{b}_m^{T_n} = [b_{m0}, b_{m1}e^{jn\alpha_1}, b_{m2}e^{jn\alpha_2}, \dots, b_{mN-1}e^{jn\alpha_{N-1}}], n = 0, 1, \dots, N-1 \quad m = 0, 1, \dots, M-1.$$

According to one embodiment of the invention, any nonzero real number or any nonzero complex number sequence can be used to generate an orthogonal code group for use in a spread spectrum communication system when appropriate rotations are applied. Also, according to one embodiment, any real number or complex number orthogonal code group can be used to generate multiple orthogonal code groups. The resulting code groups retain the same non-periodic auto-correlation and cross-correlation characteristics of the initial code group. Furthermore, the resulting code groups can satisfy various requirements of a spread spectrum multiple access communication system.

Embodiments of the present invention can be used to generate orthogonal spread spectrum multiple access code groups for use in different cells (or sectors) of a cell-based or sector-based spread spectrum multiple access communication system. The present invention offers an effective solution for network planning, switching and capacity enhancement, etc., of spread spectrum communication systems. Additionally, by applying the rotation transformation multiple times, an orthogonal code group can be quickly generated from a nonzero real number sequence or a complex number sequence of any length. The present invention, which is simple and effective, can replace the complex conventional methods for generating orthogonal codes.

Brief Description of the Drawings

For a better understanding of the invention, reference should be made to the following detailed description taken in conjunction with the accompanying drawings, in which:

Fig. 1 depicts a cellular network that uses orthogonal code groups in accordance with an embodiment of the present invention.

Fig. 2 depicts a cell within a cellular network that uses orthogonal codes in accordance with an embodiment of the present invention.

Fig. 3 is a block diagram of a transmitter that uses orthogonal codes in accordance with one embodiment of the present invention.

Fig. 4 is a block diagram of a transmitter that uses orthogonal codes in accordance with another embodiment of the present invention.

Fig. 5 is a block diagram of a receiver that uses orthogonal codes in accordance with another embodiment of the present invention.

Fig. 6 is a block diagram of a receiver that uses orthogonal codes in accordance with another embodiment of the present invention.

Description of the Preferred Embodiments

Preferred embodiments of the present invention are described below.

An embodiment of the present invention is an orthogonal rotation method for generating a group of orthogonal codes based on a code sequence. According to this embodiment, a first code sequence is chosen. Then, a plurality of basic rotation angles for the elements of the first sequence are defined. The elements are then rotated by an integer multiple of the defined basic rotation angles to form a second sequence. According to the present embodiment, the second code sequence thus generated will be orthogonal with the initial sequence. The rotation transformation may be performed multiple times with different integer multiples to form a group of orthogonal code sequences.

As an example, suppose there is a binary sequence with a length of 3 elements, + + +. In accordance with the present example, three rotation angles α_0 , α_1 and α_2 are chosen. In this example, α_0 is chosen to be 0, α_1 is chosen to be $2\pi/3$, and α_2 is chosen to be $4\pi/3$. Then, each element of the binary sequence is rotated by the corresponding rotation angles in the complex plane. That is, the first element is rotated by α_0 (0), the second element is rotated by α_1 ($2\pi/3$), and the third element is rotated by α_2 ($4\pi/3$, or, equivalently, $-2\pi/3$), respectively, in the complex plane. As a result, a new sequence $(+ e^{j2\pi/3} e^{-j2\pi/3})$ is produced.

Then, each element of the binary sequence is rotated by an integer multiple of the rotation angles α_0 , α_1 and α_2 . When the integer multiple is two, each element of the binary sequence is rotated by two times the corresponding rotation angle. So, the first element is rotated by $2 \times \alpha_0$ (0), the second element is rotated by $2 \times \alpha_1$ ($4\pi/3$ or, equivalently, $-2\pi/3$),

and the third element by $2 \times \alpha_2$ ($8\pi/3$ or, equivalently, $2\pi/3$), respectively, in the complex plane. As a result, another new sequence, $(+ e^{-j2\pi/3} e^{j2\pi/3})$, is produced. In this example, it is meaningless to apply three or more cycles of rotation because additional cycles of rotation do not produce any new sequence. Therefore, after applying two cycles of rotation on the sequence $(+ + +)$, a code group is obtained:

$$\begin{aligned} \text{Basic sequence} &= [+ + +]; \\ \text{Rotate one cycle} &= [+ e^{j2\pi/3} e^{-j2\pi/3}]; \\ \text{Rotate two cycles} &= [+ e^{-j2\pi/3} e^{j2\pi/3}]. \end{aligned}$$

This code group, formed by orthogonal rotation, is an orthogonal code group. As used herein, an orthogonal code group includes codes that are completely or nearly orthogonal with each other, that is, the sum of the products of each element of one code with the corresponding element (in some cases, the complex conjugate of the corresponding element) equals or approximately equals zero. In the above example, the code

$[+ e^{j2\pi/3} e^{-j2\pi/3}]$ is orthogonal to $[+ e^{-j2\pi/3} e^{j2\pi/3}]$ because the sum of the products of each element of $[+ e^{j2\pi/3} e^{-j2\pi/3}]$ with the complex conjugate of the corresponding element of $[+ e^{-j2\pi/3} e^{j2\pi/3}]$ equals zero.

Note that the orthogonality of the code sequences is totally independent of their initial phases. For instance, consider the following code sequences with initial phrases of φ_0 , φ_1 and φ_2 :

$$\begin{aligned} C_0(\varphi_0) &= [e^{j\varphi_0} e^{j\varphi_0} e^{j\varphi_0}] \\ C_1(\varphi_1) &= \left[e^{j\varphi_1} e^{j\left(\varphi_1 + \frac{2\pi}{3}\right)} e^{j\left(\varphi_1 - \frac{2\pi}{3}\right)} \right] \\ C_2(\varphi_2) &= \left[e^{j\varphi_2} e^{j\left(\varphi_2 - \frac{2\pi}{3}\right)} e^{j\left(\varphi_2 + \frac{2\pi}{3}\right)} \right] \end{aligned}$$

Observe that, for any initial phase φ_0 , φ_1 and φ_2 , the codes $C_0(\varphi_0)$, $C_1(\varphi_1)$ and $C_2(\varphi_2)$ remain orthogonal with each other. Because of their orthogonal characteristics, these codes can be adapted for use in a spread spectrum communication systems.

Attention now turns to the auto-correlation characteristics of the code sequences generated according to embodiments of the present invention. Auto-correlation refers to the degree of correspondence between a sequence and a phased-shifted replica of itself. An auto-correlation function for a signal $x(t)$, in general, is defined as:

$$R_x(\tau) = \int_{-\infty}^{\infty} x(t) x(t+\tau) dt$$

In some embodiments of the present invention, an auto-correlation function of a code sequence is the sum of the products of each element of the code sequence with the complex conjugate of the corresponding element of a phase-shifted replica of the code sequence. Table 1 illustrates the non-periodic auto-correlation functions of the code sequences $C_0(\varphi_0)$, $C_1(\varphi_1)$ and $C_2(\varphi_2)$.

Table 1

Non-periodic auto-correlation functions of $C_0(\varphi_0) = [e^{j\varphi_0} \ e^{j\varphi_0} \ e^{j\varphi_0}]$

$$C_1(\varphi_1) = \left[e^{j\varphi_1} \ e^{j\left(\varphi_1 + \frac{2\pi}{3}\right)} \ e^{j\left(\varphi_1 - \frac{2\pi}{3}\right)} \right] \quad C_2(\varphi_2) = \left[e^{j\varphi_2} \ e^{j\left(\varphi_2 - \frac{2\pi}{3}\right)} \ e^{j\left(\varphi_2 + \frac{2\pi}{3}\right)} \right]$$

	-2	-1	0	1	2
$R_{C_0}(\tau)$	1	2	3	2	1
$R_{C_1}(\tau)$	$e^{j2\pi/3}$	$2e^{-j2\pi/3}$	3	$2e^{j2\pi/3}$	$e^{-j2\pi/3}$
$R_{C_2}(\tau)$	$e^{-j2\pi/3}$	$2e^{j2\pi/3}$	3	$2e^{-j2\pi/3}$	$e^{j2\pi/3}$

As shown in Table 1, the auto-correlation functions $R_{co}(\tau)$, $R_{cl}(\tau)$ and $R_{cl}(\tau)$ are substantially consistent with each other except at the side lobes where some fixed phase shifts occur. The characteristic that the auto-correlation functions $R_{co}(\tau)$, $R_{cl}(\tau)$ and $R_{cl}(\tau)$ are substantially consistent with each other except at the side lobes is also desired in some spread spectrum communication systems.

5

In the following, the effects of rotation transformation on the orthogonality or bi-orthogonality of a spread spectrum code group are described. Consider the following ternary code group $\{C_0, C_1, C_2, C_3\}$:

10

$$C_0 = [+ \quad + \quad +]$$

$$C_1 = [+ \quad - \quad -]$$

$$C_2 = [- \quad - \quad +]$$

$$C_3 = [- \quad + \quad -]$$

15

Table 2 is a table showing the non-periodic auto-correlation and cross-correlation function of this code group. Cross-correlation refers to the degree of correspondence between two sequences. A cross-correlation function between two different signals, $x(t)$ and $y(t)$, in general, is given as

20

$$Rc(\tau) = \int_{-\infty}^{\infty} x(\tau)y(t+\tau)dt$$

25

In some embodiments of the present invention, a cross-correlation function between a first code sequence and a second code sequence is the sum of the products of each element of first code sequence with the complex conjugate of the corresponding element of a phase-shifted replica of the second code sequence.

30

35

Table 2

Non-periodic auto-correlation and cross-correlation functions of

 $C_0 = [+ \ + \ +]; C_1 = [+ \ - \ -]; C_2 = [- \ - \ +]; C_3 = [- \ + \ -]$

		-2	-1	0	1	2
	$R_{C_0}(\tau)$	1	2	3	2	1
	$R_{C_1}(\tau)$	-1	0	3	0	-1
	$R_{C_2}(\tau)$	-1	0	3	0	-1
10	$R_{C_3}(\tau)$	1	-2	3	-2	1
	$R_{C_0C_1}(\tau)$	-1	-2	-1	0	1
	$R_{C_0C_2}(\tau)$	1	0	-1	-2	-1
	$R_{C_0C_3}(\tau)$	-1	0	-1	0	-1
15	$R_{C_1C_2}(\tau)$	1	-2	-1	2	1
	$R_{C_1C_3}(\tau)$	-1	2	-1	0	1
	$R_{C_2C_3}(\tau)$	1	0	-1	2	-1

When rotated according to embodiments of the invention, the multiple access code group $\{C_0, C_1, C_2, C_3\}$ produces the following three groups of multiple access codes.

$$C_0^{T_0} = \begin{bmatrix} + & + & + \end{bmatrix} \quad C_0^{T_1} = \begin{bmatrix} + & e^{j2\pi/3} & e^{-j2\pi/3} \end{bmatrix} \quad C_0^{T_2} = \begin{bmatrix} + & e^{-j2\pi/3} & e^{j2\pi/3} \end{bmatrix}$$

5

$$C_1^{T_0} = \begin{bmatrix} + & - & - \end{bmatrix} \quad C_1^{T_1} = \begin{bmatrix} + & e^{-j\pi/3} & e^{j\pi/3} \end{bmatrix} \quad C_1^{T_2} = \begin{bmatrix} + & e^{j\pi/3} & e^{-j\pi/3} \end{bmatrix}$$

10

$$C_2^{T_0} = \begin{bmatrix} - & - & + \end{bmatrix} \quad C_2^{T_1} = \begin{bmatrix} - & e^{-j\pi/3} & e^{-j2\pi/3} \end{bmatrix} \quad C_2^{T_2} = \begin{bmatrix} - & e^{j\pi/3} & e^{j2\pi/3} \end{bmatrix}$$

$$C_3^{T_0} = \begin{bmatrix} - & + & - \end{bmatrix} \quad C_3^{T_1} = \begin{bmatrix} - & e^{j2\pi/3} & e^{j\pi/3} \end{bmatrix} \quad C_3^{T_2} = \begin{bmatrix} - & e^{-j2\pi/3} & e^{-j\pi/3} \end{bmatrix}$$

15

(initial code group)

(rotate one cycle)

(rotate two cycles)

It is easy to verify that these codes, before and after rotation transformation, are thoroughly orthogonal, i.e., $R_{C_i^{T_k} C_l^{T_l}}(0) \equiv 0$ where $i, l = 0, 1, 2 \quad k \neq l$. Four orthogonal code groups are formed by orthogonal rotation.

20

Group 1

Group 2

25

$$C_0^{T_0} = \begin{bmatrix} + & + & + \end{bmatrix}$$

$$C_1^{T_0} = \begin{bmatrix} + & - & - \end{bmatrix}$$

$$C_0^{T_1} = \begin{bmatrix} + & e^{j2\pi/3} & e^{-j2\pi/3} \end{bmatrix}$$

$$C_1^{T_1} = \begin{bmatrix} + & e^{-j\pi/3} & e^{j\pi/3} \end{bmatrix}$$

30

$$C_0^{T_2} = \begin{bmatrix} + & e^{-j2\pi/3} & e^{j2\pi/3} \end{bmatrix};$$

$$C_1^{T_2} = \begin{bmatrix} + & e^{j\pi/3} & e^{-j\pi/3} \end{bmatrix}$$

35

Group 3

$$\mathbf{C}_2^{T_0} = \begin{bmatrix} - & - & + \end{bmatrix}$$

$$\mathbf{C}_2^{T_1} = \begin{bmatrix} - & e^{-j\pi/3} & e^{-j2\pi/3} \end{bmatrix}$$

$$\mathbf{C}_2^{T_2} = \begin{bmatrix} - & e^{j\pi/3} & e^{j2\pi/3} \end{bmatrix};$$

Group 4

$$\mathbf{C}_3^{T_0} = \begin{bmatrix} - & + & - \end{bmatrix}$$

$$\mathbf{C}_3^{T_1} = \begin{bmatrix} - & e^{j2\pi/3} & e^{j\pi/3} \end{bmatrix}$$

$$\mathbf{C}_3^{T_2} = \begin{bmatrix} - & e^{-j2\pi/3} & e^{-j\pi/3} \end{bmatrix}$$

Tables 3 and 4 show the non-periodic auto-correlation and cross-correlation functions of the codes formed by the same number of rotation cycles. Table 3 shows the non-periodic auto-correlation and cross-correlation functions of $\mathbf{C}_0^{T_1}$ $\mathbf{C}_1^{T_1}$ $\mathbf{C}_2^{T_1}$ and $\mathbf{C}_3^{T_1}$. Table 4 shows the non-periodic auto-correlation and cross-correlation functions of $\mathbf{C}_0^{T_2}$ $\mathbf{C}_1^{T_2}$ $\mathbf{C}_2^{T_2}$ and $\mathbf{C}_3^{T_2}$. It can be seen from Tables 3 and 4 that, except for some fixed phase shifts at the side lobes of the correlation functions, the auto-correlation and cross-correlation functions of the codes of the initial code group are substantially consistent with those of the codes in the orthogonal-rotation generated code groups.

Table 3

Non-periodic auto-correlation and cross-correlation functions of

$$\mathbf{C}_{T_0}^{T_1} = \begin{bmatrix} + & e^{j2\pi/3} & e^{-j2\pi/3} \end{bmatrix} \quad \mathbf{C}_{T_1}^{T_1} = \begin{bmatrix} + & e^{-j\pi/3} & e^{j\pi/3} \end{bmatrix}$$

$$\mathbf{C}_{T_2}^{T_1} = \begin{bmatrix} - & e^{-j\pi/3} & e^{-j2\pi/3} \end{bmatrix} \quad \mathbf{C}_{T_3}^{T_1} = \begin{bmatrix} - & e^{j2\pi/3} & e^{j\pi/3} \end{bmatrix}$$

		-2	-1	0	1	2
10	$R_{C_0}(\tau)$	$e^{j2\pi/3}$	$2e^{-j2\pi/3}$	3	$2e^{j2\pi/3}$	$e^{-j2\pi/3}$
	$R_{C_1}(\tau)$	$e^{-j\pi/3}$	0	3	0	$e^{j\pi/3}$
	$R_{C_2}(\tau)$	$e^{-j\pi/3}$	0	3	0	$e^{j\pi/3}$
15	$R_{C_3}(\tau)$	$e^{j2\pi/3}$	$2e^{j\pi/3}$	3	$2e^{-j\pi/3}$	$e^{-j2\pi/3}$
	$R_{C_0C_1}(\tau)$	$e^{-j\pi/3}$	$2e^{j\pi/3}$	-1	0	$e^{-j2\pi/3}$
	$R_{C_0C_2}(\tau)$	$e^{j2\pi/3}$	0	-1	$2e^{-j\pi/3}$	$e^{j\pi/3}$
20	$R_{C_0C_3}(\tau)$	$e^{-j\pi/3}$	0	-1	0	$e^{j\pi/3}$
	$R_{C_1C_2}(\tau)$	$e^{j2\pi/3}$	$2e^{j\pi/3}$	-1	$2e^{j2\pi/3}$	$e^{-j2\pi/3}$
25	$R_{C_1C_3}(\tau)$	$e^{-j\pi/3}$	$2e^{-j2\pi/3}$	-1	0	$e^{-j2\pi/3}$
	$R_{C_2C_3}(\tau)$	$e^{j2\pi/3}$	0	-1	$2e^{j\pi/3}$	$e^{j\pi/3}$

Table 4

Non-periodic auto-correlation and cross-correlation functions of

$$C_0^{T_2} = \begin{bmatrix} + & e^{-j2\pi/3} & e^{j2\pi/3} \end{bmatrix} \quad C_1^{T_2} = \begin{bmatrix} + & e^{j\pi/3} & e^{-j\pi/3} \end{bmatrix}$$

$$C_2^{T_2} = \begin{bmatrix} - & e^{j\pi/3} & e^{j2\pi/3} \end{bmatrix} \quad C_3^{T_2} = \begin{bmatrix} - & e^{-j2\pi/3} & e^{-j\pi/3} \end{bmatrix}$$

		-2	-1	0	1	2
10	$R_{C_0}(\tau)$	$e^{-j2\pi/3}$	$2e^{j2\pi/3}$	3	$2e^{-j2\pi/3}$	$e^{j2\pi/3}$
	$R_{C_1}(\tau)$	$e^{j\pi/3}$	0	3	0	$e^{-j\pi/3}$
	$R_{C_2}(\tau)$	$e^{j\pi/3}$	0	3	0	$e^{-j\pi/3}$
15	$R_{C_3}(\tau)$	$e^{-j2\pi/3}$	$2e^{-j\pi/3}$	3	$2e^{j\pi/3}$	$e^{j2\pi/3}$
	$R_{C_0C_1}(\tau)$	$e^{j\pi/3}$	$2e^{-j\pi/3}$	-1	0	$e^{j2\pi/3}$
	$R_{C_0C_2}(\tau)$	$e^{-j2\pi/3}$	0	-1	$2e^{j\pi/3}$	$e^{-j\pi/3}$
20	$R_{C_0C_3}(\tau)$	$e^{j\pi/3}$	0	-1	0	$e^{-j\pi/3}$
	$R_{C_1C_2}(\tau)$	$e^{-j2\pi/3}$	$2e^{-j\pi/3}$	-1	$2e^{-j2\pi/3}$	$e^{j2\pi/3}$
25	$R_{C_1C_3}(\tau)$	$e^{j\pi/3}$	$e^{j\pi/3}$	-1	0	$e^{j2\pi/3}$
	$R_{C_2C_3}(\tau)$	$e^{-j2\pi/3}$	0	-1	$2e^{-j2\pi/3}$	$e^{-j\pi/3}$

As described above, an orthogonal code group can be formed by orthogonal rotation of a nonzero sequence of length N such as $\mathbf{a}_0 = [a_{00}, a_{01}, a_{02}, \dots, a_{0N-1}]$. In furtherance of an embodiment of the invention, if every element in the sequence a_{0n} ($n = 0, 1, 2, \dots, N-1$) is a real number with equal absolute value, or a complex

number with equal modulus value (i.e., $|a_{0n}|^2$ equals a constant), then a constant rotation can be applied.

In this embodiment, according to the code length the basic rotation angles are defined as $\alpha_k = \frac{2k\pi}{N}$ ($k = 0, 1, \dots, N-1$). These basic rotation angles can be used to produce (N-1) new code sequences, including:

$$\begin{aligned} \mathbf{a}_1(\varphi_1) &= [a_{00}e^{j\varphi_1}, a_{01}e^{j(\varphi_1+\alpha)}, a_{02}e^{j(\varphi_1+2\alpha)}, \dots, a_{0N-1}e^{j[\varphi_1+(N-1)\alpha]}] \\ \mathbf{a}_2(\varphi_2) &= [a_{00}e^{j\varphi_2}, a_{01}e^{j(\varphi_2+2\alpha)}, a_{02}e^{j(\varphi_2+4\alpha)}, \dots, a_{0N-1}e^{j[\varphi_2+2(N-1)\alpha]}] \\ &\vdots \\ \mathbf{a}_{N-1}(\varphi_{N-1}) &= [a_{00}e^{j\varphi_{N-1}}, a_{01}e^{j(\varphi_{N-1}+(N-1)\alpha)}, a_{02}e^{j(\varphi_{N-1}+2(N-1)\alpha)}, \dots, a_{0N-1}e^{j[\varphi_{N-1}+(N-1)^2\alpha]}] \end{aligned}$$

The symbols $\varphi_1, \varphi_2, \dots, \varphi_{N-1}$ represent initial phase angles. Furthermore, a_0 may also have an initial phase angle φ_0 . That is,

$$\mathbf{a}_0(\varphi_0) = [a_{00}e^{j\varphi_0}, a_{01}e^{j\varphi_0}, a_{02}e^{j\varphi_0}, \dots, a_{0N-1}e^{j\varphi_0}].$$

Together with the initial sequence, there are N sequences:

$\mathbf{a}_0(\varphi_0), \mathbf{a}_1(\varphi_1), \mathbf{a}_2(\varphi_2), \dots, \mathbf{a}_{N-1}(\varphi_{N-1})$. According to the present embodiment, these sequences constitute an orthogonal code group.

If $|a_{0n}|^2$ ($n = 0, 1, 2, \dots, N-1$) does not equal a constant, e.g., $|a_{0n}|^2$ is not the same for all elements of a sequence, then it would be impossible to have a constant rotation. For simplicity, assuming there are no initial phase angles, N-1 new sequences are produced after orthogonal rotations. These sequences include:

$$\begin{aligned} \mathbf{a}_1 &= [a_{00}, a_{01}e^{j\alpha_1}, a_{02}e^{j\alpha_2}, \dots, a_{0N-1}e^{j\alpha_{N-1}}] \\ \mathbf{a}_2 &= [a_{00}, a_{01}e^{j2\alpha_1}, a_{02}e^{j2\alpha_2}, \dots, a_{0N-1}e^{j2\alpha_{N-1}}] \\ &\vdots \end{aligned}$$

$$\mathbf{a}_{N-1} = [a_{00}, a_{01} e^{j(N-1)\alpha_1}, a_{02} e^{j(N-1)\alpha_2}, \dots, a_{0N-1} e^{j(N-1)\alpha_{N-1}}]$$

The values of the basic rotation angles $\alpha_1 \alpha_2 \dots \alpha_{N-1}$ can be determined by solving the following set of equations:

$$\begin{cases} |a_{00}|^2 + |a_{01}|^2 e^{j\alpha_1} + |a_{02}|^2 e^{j\alpha_2} + \dots + |a_{0N-1}|^2 e^{j\alpha_{N-1}} = 0 \\ |a_{00}|^2 + |a_{01}|^2 e^{j2\alpha_1} + |a_{02}|^2 e^{j2\alpha_2} + \dots + |a_{0N-1}|^2 e^{j2\alpha_{N-1}} = 0 \\ \vdots \\ |a_{00}|^2 + |a_{01}|^2 e^{j(N-1)\alpha_1} + |a_{02}|^2 e^{j(N-1)\alpha_2} + \dots + |a_{0N-1}|^2 e^{j(N-1)\alpha_{N-1}} = 0 \end{cases}$$

The set of equations have N-1 unknowns $\alpha_1, \alpha_2, \dots, \alpha_{N-1}$. Since there are N-1 non-equivalent equations and N-1 unknowns, the equations are solvable. The initial phase of every sequence, $\varphi_0, \varphi_1, \varphi_2, \dots, \varphi_{N-1}$, does not affect the orthogonal rotation.

Therefore, it is unnecessary to consider the initial phase angles when solving the equations.

According to another embodiment of invention, multiple orthogonal code groups can be generated from an initial orthogonal code group. In this embodiment, an orthogonal code group \mathbf{B}^{T_0} with M sequences each having a length of N is chosen. By definition, the sequences of the orthogonal code group \mathbf{B}^{T_0} , are orthogonal with each other.

$$\mathbf{B}^{T_0} = \begin{bmatrix} \mathbf{b}_0^{T_0} \\ \mathbf{b}_1^{T_0} \\ \vdots \\ \mathbf{b}_m^{T_0} \\ \vdots \\ \mathbf{b}_{M-1}^{T_0} \end{bmatrix}, \text{ where } \mathbf{b}_m^{T_0} = [b_{m0}, b_{m1}, \dots, b_{mN-1}] \text{ and}$$

$$m = 0, 1, 2, \dots, M-1.$$

Then, according to the present embodiment, a plurality of basic rotation angles are defined. Then, orthogonal rotations are applied to every sequence of the code group to generate a new code group.

The initial code group \mathbf{B}^{T_0} can be rotated (N-1) times with (N-1) different integer multiples of the basic rotation angles to produce (N-1) new orthogonal code groups. Together with the initial code group \mathbf{B}^{T_0} , there are N code groups:

$$\mathbf{B}^{T_0}, \mathbf{B}^{T_1}, \mathbf{B}^{T_2}, \dots, \mathbf{B}^{T_{N-1}},$$

$$\text{where } \mathbf{B}^{T_n} = \begin{bmatrix} \mathbf{b}_0^{T_n} \\ \mathbf{b}_1^{T_n} \\ \vdots \\ \mathbf{b}_{M-1}^{T_n} \end{bmatrix}, \mathbf{b}_m^{T_n} = [b_{m0}, b_{m1}e^{jn\alpha_1}, b_{m2}e^{jn\alpha_2}, \dots, b_{mN-1}e^{jn\alpha_{N-1}}].$$

$$n = 0, 1, 2, \dots, N-1, \text{ and } m = 0, 1, 2, \dots, M-1.$$

Here, \mathbf{B}^{T_n} ($n = 0, 1, 2, \dots, N-1$) represents the resulting code group after the n^{th} orthogonal rotation, and \mathbf{B}^{T_0} represents the initial code group. When every element of the sequence $\mathbf{b}_m^{T_0}$ is a real number with equal absolute value, or a complex number with equal modulus value (i.e., $|b_{mn}|^2$ equals a constant), or contains real number elements and complex number elements having the same modulus value, then a constant rotation can be applied. When constant rotation is applied, the basic rotation angles can be determined by:

$$\alpha_k = \frac{2k\pi}{N}, \text{ where } k = 1, 2, \dots, N-1.$$

If $|b_{mn}|^2$ is not a constant, the basic rotation angles $\alpha_1 \quad \alpha_2 \quad \dots \quad \alpha_{N-1}$ cannot be determined by the above formula. Rather, the basic rotation angles can be determined by solving the following set of equations:

$$\begin{cases} |b_{m0}|^2 + |b_{m1}|^2 e^{j\alpha_1} + |b_{m2}|^2 e^{j\alpha_2} + \dots + |b_{mN-1}|^2 e^{j\alpha_{N-1}} = 0 \\ |b_{m0}|^2 + |b_{m1}|^2 e^{j2\alpha_1} + |b_{m2}|^2 e^{j2\alpha_2} + \dots + |b_{mN-1}|^2 e^{j2\alpha_{N-1}} = 0 \\ \vdots \\ |b_{m0}|^2 + |b_{m1}|^2 e^{j(N-1)\alpha_1} + |b_{m2}|^2 e^{j(N-1)\alpha_2} + \dots + |b_{mN-1}|^2 e^{j(N-1)\alpha_{N-1}} = 0 \end{cases},$$

where $m = 0, 1, \dots, M - 1$.

Note that the solution of the equations is independent of m . Therefore, the above set of equations can be solved with any permissible value of m .

Orthogonal code groups generated according to embodiments of the present invention can be used in a wide variety of communication systems. For example, orthogonal code groups generated according to embodiments of the present invention can be used in a cellular wireless communication network in which a certain cell uses one orthogonal code group while other another cell use another orthogonal code group. Fig. 1 depicts a portion of such a wireless communication network 100 that has a number of cells 111-114 each using a different orthogonal code group. Specifically, as illustrated, cell 110 uses orthogonal code group B^{T_0} , while cell 112 uses orthogonal code group B^{T_2} , etc., where the code groups $B^{T_1}, B^{T_2}, \dots, B^{T_4}$ are generated according to embodiments of the

present invention of B^{T_0} , where $B^{T_k} = \begin{bmatrix} \mathbf{b}^{T_k}_0 \\ \mathbf{b}^{T_k}_1 \\ \vdots \\ \mathbf{b}^{T_k}_m \\ \vdots \\ \mathbf{b}^{T_k}_{M-1} \end{bmatrix}$,

$$\mathbf{b}^{T_k}_m = [b_{m0}, b_{m1}e^{jk\alpha_2}, b_{m2}e^{jk\alpha_2}, \dots, b_{mN-1}e^{jk\alpha_{N-1}}],$$

$[b_{m0}, b_{m1}, b_{m2}, \dots, b_{mN-1}]$ denotes a base spread spectrum code,

$\alpha_1, \alpha_2, \dots, \alpha_{N-1}$ denote a set of basic rotation angles, where k denotes an integer, and m denotes an integer smaller than $M-1$. As discussed above, provided the basic code group

B^{T_0} is an orthogonal code group, the code groups generated according to embodiments of the present invention will also be orthogonal code groups. Furthermore, the code groups thus generated retain desirable characteristics (e.g., auto-correlation and cross-correlation characteristics) of the initial code group B^{T_0} .

According to another embodiment of the present invention, codes generated according to embodiments of the present invention can be used within a same cell of a communication network. A cell 200 that uses an orthogonal code group A is illustrated in Fig. 2. In the present example, code sequences of the orthogonal code group A assume the form:

5 $[a_0, a_1 e^{jk\alpha_1}, a_2 e^{jk\alpha_2}, \dots, a_{N-1} e^{jk\alpha_{N-1}}]$, where $k = 0, 1, 2, \dots$, where

$[a_0, a_1, a_2, \dots, a_{N-1}]$ denotes a base spread spectrum code sequence, where

$\alpha_1, \alpha_2, \dots, \alpha_{N-1}$ denote a set of pre-defined basic rotation angles, and where k denotes an

10 integer.

Also illustrated in Fig. 2 are base station 210 and two mobile units 214 and 216 located within the cell 200. While mobile unit 214 can communicate with base station 210 using one code a_1 of the orthogonal code group A, mobile unit 216 can communicate with the base station 210 using another code a_7 of the same orthogonal code group. Code a_1 and code a_7 , which are generated according to embodiments of the present invention from a pre-determined code $[a_0, a_1, a_2, \dots, a_{N-1}]$, are substantially orthogonal with each other and retain desirable characteristics of the pre-determined code. Because of their orthogonality, interference between the two communication channels is low.

Fig. 3 depicts a block diagram of a transmitter 300 for a wireless communication system according to an embodiment of the present invention. The transmitter 300 may be implemented as part of a base station (e.g., base station 210) or a mobile station (e.g., mobile unit 214). As depicted, transmitter 300 includes a code generator 310 that stores a pre-determined code $[a_0, a_1, a_2, \dots, a_{N-1}]$ (312) and a set of pre-determined basic rotation angles $\alpha_1, \alpha_2, \dots, \alpha_{N-1}$ (314). Using the pre-determined code, the pre-determined basic rotation angles, and embodiments of the orthogonal rotation process discussed above, the code generator 310 generates an orthogonally rotated code a_0 that includes the elements $[a_0, a_1 e^{jk\alpha_1}, a_2 e^{jk\alpha_2}, \dots, a_{N-1} e^{jk\alpha_{N-1}}]$. The code a_0 is

then provided to a spreader circuit 320, which uses the code a_0 to spread the data to be transmitted. The spread data is then filtered by filter 330 and modulated by a carrier frequency 340. The modulated data is then filtered, amplified and transmitted via antenna

370. Note that the transmitter 300 of Fig. 3 has a configuration that is well known in the art. Many other configurations consistent with the scope and principles of the present invention are also possible.

With reference still to Fig. 3, different codes can be dynamically generated using
 5 different integer multiples of the basic rotation angles. Thus, the transmitter 300 may be dynamically configured to use codes that are not already used by other transmitters in the vicinity.

Fig. 4 depicts a block diagram of a simple transmitter 400 for a wireless
 10 communication system according to another embodiment of the present invention. The transmitter 400 does not use a code generator for generating the codes. Rather, the transmitter 400 uses a memory 410 having stored therein multiple code
 groups $B^{T_0}, B^{T_1}, B^{T_2} \dots B^{T_L}$ (412) that are generated according to embodiments of the
 15 present invention disclosed above. Selection signals can be used to select a particular one of the codes of the code groups to be used by the transmitter 400 to spread the data to be transmitted. In other respects, the components and the operation of transmitter 400 are the same as those of transmitter 300.

Fig. 5 depicts a block diagram of a receiver 500 for a wireless communication
 20 system according to an embodiment of the present invention. The receiver 500 may be used to receive data transmitted by transmitter 300 or 400, and may be implemented as part of a base station or a mobile station of the communication system. In Fig. 5, signals received by the receiver 500 are demodulated, and despread by a code \mathbf{a}_0 , which is generated by a code
 25 generator according to a pre-determined code $[a_0, a_1, a_2, \dots, a_{N-1}]$ (312), a set of pre-determined basic rotation angles $\alpha_1, \alpha_2, \dots, \alpha_{N-1}$ (314), and embodiments of the orthogonal rotation process discussed above.

Fig. 6 depicts a block diagram of a receiver 600 for a wireless communication
 30 system according to another embodiment of the present invention. The receiver 600 may be used to receive data transmitted by transmitter 300 or 400, and may be implemented as part of a base station or a mobile station of the communication system. Pre-generated codes and/or code groups $B^{T_0}, B^{T_1}, B^{T_2} \dots B^{T_L}$ (412) are stored in a memory unit (410) of the
 35 receiver 600. In Fig. 6, a code \mathbf{a}_0 , which is one of the codes stored in the memory unit 410,

is selected and used to despread received data. In other respects, the components and operation of receiver 600 are the same as those of receiver 500.

The foregoing description, for purposes of explanation, used specific nomenclature to provide a thorough understanding of the invention. However, it will be apparent to one skilled in the art that the specific details are not required in order to practice the invention. In other instances, well known circuits and devices are shown in block diagram form in order to avoid unnecessary distraction from the underlying invention. Thus, the foregoing descriptions of specific embodiments of the present invention are presented for purposes of illustration and description. They are not intended to be exhaustive or to limit the invention to the precise forms disclosed, obviously many modifications and variations are possible in view of the above teachings. The embodiments were chosen and described to best explain the principles of the invention and its practical applications, to thereby enable others skilled in the art to best utilize the invention and various embodiments with various modifications as are suited to the particular use contemplated.

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